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THE AMERICAN

METEOROLOGICAL JOURNAL.

VOL. VII. ANN ARBOR, FEBRUARY, 1891. NO. 10.

ORIGINAL ARTICLES.

THE STATE WEATHER SERVICE.*

BY FRANCIS E. NIPHER.

The first proposition to distribute weather warnings by telegraph for the benefit of commerce and agriculture, was made by Lieutenant Maury, a man whose name was a household word before the war, and whose scientific services to the country have never been excelled.

The plan was carried out on a large scale soon after the war by the signal corps of the army, which was reorganized by General Meyer for that service.

In comparing our weather service with those of countries like England, Germany, Norway, Sweden, it should be remembered that they have areas comparable with those of states like Missouri.

For the prediction of large storms, like those which characterize our winter months, the vast extent of our national area is of great advantage. But many storms are local in their character, and to study and predict such storms, over so vast an area, from a single office, is a very difficult task indeed. It has never been satisfactorily done.

Moreover, the study of the climate of states can be best done by the states themselves. Recognizing these difficulties of the national service, Dr. Hinrichs, then a citizen of Iowa, organized

*—Delivered by request of the State Board of Agriculture in Representative Hall, Jefferson City, Mo., January 15, 1891.

the Iowa Weather Service about fifteen years ago, and shortly afterward the Missouri Weather Service was organized by myself. For a number of years these two state services were the only ones in existence in the country.

The Missouri Weather Service I have continued up to the present time, and it is now being conducted wholly on private means. In the meantime, such services have been started in many other states, and their number is increasing in a very gratifying way. Many of the states have made liberal appropriations for them, and there is little doubt that finally each state will be furnished with a well-supported weather service.

There are always many intelligent persons in each state who take an interest in weather observations, and who take an honest pride in coöperating with a public service. The people of the country are not yet all wholly given to money-getting. I have found them in many cases willing to expend considerable amounts for instruments. The daily work of the observer requires only a few minutes, but it is a constant care. If he is absent for a day it is necessary for him to provide for the making of the observations in his absence. When men of this kind can be found who are willing to render a valuable service to the state free of charge, they ought to be encouraged. That kind of statesmen are not by any means too numerous.

The state weather service should aim to study the climate of the state, with particular reference to the crops that are grown. What are the conditions of weather which cause insect pests to thrive? How frequently do the weather conditions cause ruinous damage? Does it therefore pay to raise certain crops, and may we more profitably give our attention to other crops more suited to our conditions? These are questions which should be examined by an appeal to weather records and market and crop reports.

Bridge and railway engineers are interested in knowing how frequently rains of three, four, five, or six inches may fall in a single hour. How frequently does it rain for three hours at the rate of two inches an hour? Until such questions can be answered with reasonable precision, the dimensions most suitable for culverts and waterways, for railroad and highway bridges, can only be rudely estimated.

If the water supply of a city is partly or wholly derived from rainfall, it is most important to have authoritative records of

severe drouths. In no other way can the proper storage capacity of the reservoir be determined.

Such records of the climate of different states should be furnished to the national service, which should combine the work of all the states and make up the rain and temperature charts for the entire country.

The work of weather prediction has thus far been carried on only by the national service. At first the country was divided into divisions comprising several states, as the Upper Mississippi valley, the Lower Ohio valley, etc. There has, however, been a demand for predictions of a more local character, and the national service has attempted to meet this demand. The predictions are now made for each state. Evidently, however, the difficulty of making weather predictions from a single office increases very rapidly as the predictions become more local in their character, and for two reasons. In the first place, the time that can be given to the predictions by a single officer is only about one minute for each state. He glances over the network of pressure and temperature lines, he notes the regions where rain may have fallen, he sees how the conditions have been changing since the last map was made, and by a sort of intuition, and perhaps without being always able to give definite reasons for his conclusions, he makes up our weather to the best of his knowledge and belief. The more local his predictions are, the less will be his time for considering the conditions in any one locality.

Further, the phenomena increase amazingly in complexity as we come to consider minute details. We all have a fair idea of the general topography of our country, so long as we confine our attention to its grand outlines. Rising from the eastern ocean, the surface culminates in a mountain range stretching from near the Gulf of Mexico to New England. To the west we have a descending slope to the Mississippi river; then comes another rising slope, the great plains, the western mountain ranges, and a descent to the sea. Suppose, now, we come to consider the matter more minutely. We shall soon be lost in a mass of details which it is absolutely impossible for any one man to picture in his mind, as we can all picture the grand features of topography. Nevertheless, the hills on our farms are important matters to us, and they concern us more directly and constantly than does the Mississippi valley or the Allegheny mountains.

In a similar way must it remain forever impossible for any one man to give us the information we should have in regard to the weather. He can form a general idea of the movement of the larger storms and cold waves which are common in winter, and such information is of vast importance to many people. The movement of thousands of tons of meats, fruits and vegetables is controlled wholly by the weather reports. On the approach of warmer weather meats are hurried into cold-storage warehouses, and the opportunity to ship other provisions which must be kept from freezing is anticipated and made available.

But the storms which are of the greatest interest to the farmer are the local rains of summer. They surprise him with his hay down, and they destroy or damage his crop. They are very local in their character, often expending themselves over a few counties. Sometimes these rain-storms travel over a belt of country twenty-five to fifty miles in breadth, and extend across a state. You see a heavy bank of cloud edging up against a brisk wind. As it approaches you see that its front is margined below with long streamers, and above is tumbled into rounded heaps by the winds. The deep rumble of thunder increases to a roar. Suddenly the wind, which has been blowing toward the storm, ceases, as you pass through a belt of upward currents which margin the cloud-front, and then, with a mighty rush of roaring wind and beating rain, the storm is upon us. The wind gradually lessens, the clouds show a smooth leaden hue, the rain sets in steadily for an hour or more, during which the wind backs around into its original direction. The cloud finally begins to disperse and the storm is over.

Not a season passes that single storms of this kind do not inflict enough of preventable damage to pay the annual expense of a state weather service. But it is impossible for the Washington office to predict storms of this kind for the whole country. It is absolutely out of the question. No one man can mentally picture the meteorology of the country down to such minute details. Such work must be done by a local weather service, and it can be so done.

The national weather service now issues predictions which often read—"Local rains in Missouri." Now it is not of great importance to a farmer in Saline county who has cured hay spread over his field as the mower left it, that merchants and other good people in Sedalia, Hannibal or St. Louis should read

in their morning papers, that there will be local rains in Missouri.

The farmer is not in communication with these people, or with the Washington office, and hence cannot share the joy of this discovery.

And furthermore, such predictions would be of very little value to any farmer, even if they could be laid upon his table each morning. Such rains may occur here and there in a few counties, but there is little gain in setting all the people of the state into motion in preparing for a rain, which will affect perhaps only a small portion of them. The result is that people who can get such weather predictions, pay little attention to them, because they have learned by experience that this simply means, it may rain in our particular locality, and it may not, a thing which they know fairly well without the aid of any weather predictions.

But such predictions from the national weather service with data giving the general conditions of the weather, would be of great value to a local weather service, and I wish to give a brief sketch of how they may and will be utilized in the near future.

It will be but a short time when the broad patents on the telephone will expire. This will have little effect on the large telephone systems of great cities, but it will undoubtedly compel a decrease in telephone rates in smaller cities, so that farmers can afford to use them. In such places it will be possible for competing systems to start, for the use of farmers, and the tradesmen will go with the farmers. I do not anticipate such competition, as telephone people are good business men, and they will hold their ground by reducing their rates to fifteen or twenty dollars a year for farmers. Under such conditions any farmer could afford to place a telephone in his house. The value to him is evident enough. He can keep continually informed of the markets. He will never stand on the streets with a load of hay waiting for a customer, and wishing that his hay were home again. He will know before he starts from home, who will buy his produce, and what he will get for it, and he will keep it in his barn until he gets his price. During the busy time of harvest if his reaper breaks down, he can learn whether the new casting which he needs can be secured in town, and if not, he can order it. The grocer and butcher will fill his orders, and delivery men who make this their business will each morning make up a route to deliver his goods, bring his mail,

and perform any other service which he may desire. In addition to this he may at any time get the weather reports. The local weather service can, during the harvest season, receive information of the appearance of any storm, and can telephone the proper warning to the county seats, where such information should be sent. The telephone companies will receive and transmit such warnings to their subscribers, in order to increase the value of their service, and induce people to use their telephones. A warning of rain can be rung on all the call bells by a code of signals. Many of the subscribers will be prepared for a rain, and to them this warning will be sufficient. If a farmer wishes to know more about the situation, in order to be better able to decide his plans, he may call up the central office at the county seat, and learn that it is now raining in all the counties to the west, and apparently a general rain is coming in about two hours. No thoughtful man can fail to be impressed with the profound influence which the telephone is destined to exert upon the condition of the farmer. It is perfectly apparent that all of these advantages, with many others, are entirely within his reach as soon as the telephone ceases to be a monopoly. That the service can then be rendered at a price such that no enterprising farmer can afford to be without his telephone is equally certain.

The inauguration of such a system of harvest storm warnings will necessarily be done gradually. It can be best done by a weather service supported by the state. Some one must take hold of the matter and show that it can be done. At present such a weather service should have the necessary means to make a study of local summer rains. They have as yet received little study. The state weather service should secure correspondents in each county, who should be provided with blanks for recording the time of beginning and ending of each storm, the direction of motion of the cloud, the amount of rain, and such other features as may be observed. Such reports would, in a few years, give a good knowledge of the behavior of summer storms. By that time it will be feasible to inaugurate the plan which I have roughly outlined.

This is not the first time I have been here to advocate this cause. In 1883, and again during the last legislative session, I made a similar presentation of this plan. It has been my dream for thirteen years, and I have expended many hard-earned dollars in trying to bring the plan to completion. It may be

that the State Board of Agriculture can succeed in securing the inauguration of a measure, which I as a humble citizen have thus far failed to bring about as I had wished. I am here, gentlemen of the legislature, to urge upon you to entrust this work to their hands. I gladly step aside, and transfer to them the interest which has been mine, and trust that they will secure the coöperation of the public and the support of the state. It is not a small or an unimportant matter which we are considering, and it is not an untried scheme. It is simply supplemental to what is now being done by the national service. The work laid out for the state service is work which the national service is not doing, and cannot do, but it is a work in which the national service can greatly aid by coöperation with states which show a disposition to help themselves.

WIND PRESSURES AND THE MEASUREMENT OF WIND VELOCITIES.

By Professor C. F. Marvin.

I.—Measurement of Wind Velocities.

Within recent years several different experimenters have independently worked upon the problem of determining the relations between the rate of rotation of the cups of the Robinson anemometer and the velocity of the wind.

The most noteworthy experiments* have, without exception, been made upon whirling machines. In earlier experiments so many errors have arisen, due to the influence exercised by the whirling machine in stirring up and setting the air itself in motion, that considerable uncertainty exists in respect to results thus obtained. To avoid or, at least, lessen these errors, it is necessary to use whirling machines of very large dimensions. In 1888 experiments with such apparatus were begun at about the same time in both England and the United States. The machine used by Messrs. Whipple and Dines in England was set up in the open air and is still in use in carrying on in a very ingenious manner experiments upon wind pressures. The length of the whirling arm in this case was about 29 feet.

In the experiments made in this country under the direction

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* Robinson, Phil. Trans. CLXIX, 1878. pp 777–822
Stokes, Proc. Roy. Soc. XXXIX. 1881. pp 170–188.
Dohrandt, Rep. für Met., Band VI, No. 5.

of the Chief Signal Officer, and which were carried out under circumstances more favorable than any yet obtained, the arm of the whirling machine was 35 feet long for many of the experiments, and for others was shortened to 28 feet. This very large apparatus was placed in a completely closed court of large dimensions, and at the time of experimentation no air currents except those produced by the machine itself could be detected by the most delicate indicators. In these experiments the effects of currents set up by the motion of the whirling machine itself were very small, but were accurately determined by a new method which it is believed gives the best results thus far obtained. A brief explanation may make the circumstances more clear. As the large whirler with the anemometer is made to revolve, the air immediately surrounding it is pushed or dragged along with the arm to a certain extent, so that the actual movement of the anemometer through the air is somewhat less than the apparent movement. This actual movement was measured by placing a special very small and delicate anemometer in front of the anemometer being tested, and observing on the former the actual velocity of rotation of the arm. The constants of the delicate anemometer are, for this purpose, previously determined with great accuracy, a result easily obtained, as the small size of the anemometer not only admits of its being carried by a slender support at a distance of several feet from the whirling arm and entirely beyond the influence of disturbances produced by the arm, but the very rapid rate of revolution of the cups enables accurate measurements to be made in a very short time, and with only one or two revolutions of the large whirler. A more complete discussion of the methods used and the results obtained has been given in the *Signal Service Monthly Weather Review* for February, 1889.

Subsequent to the experiments upon the whirling machine an extended study has been made of the comparison of different anemometers when similarly exposed in the open air. Very early in this study I was led to the belief that the very sudden and continuous changes of considerable magnitude in the velocity of ordinary winds led to a noticeably different action of the anomometer than would result from the influence of steady currents. So far as I am aware, this important element has not thus far been considered, either in the development of a mathematical theory for the anemometer or in the final reduction of experimental results. Some mention and discussion of the sub-

ject first appeared in the AMERICAN METEOROLOGICAL JOURNAL of April, 1889.

As the matter only came to my attention after the experiments with the whirling apparatus were completed, it was impossible to make it a subject of direct experiment, but it is hoped to be able shortly to again take up the whirling machine work, in anticipation of which a new line of experiment bearing directly upon this subject has been devised. The condition which it is necessary to secure is, to propel the anemometer through still air with a highly and constantly varying velocity, for which purpose the whirling arm will be arranged with an independently revolving plate, or reciprocating lever, at the outer end, the resultant motion of which combination will have the desired irregular character.

In the absence of whirling machine experiments of this kind, the open air comparisons were reduced upon the basis that the sudden variations in wind velocities produce a less influence upon anemometers of compact proportion than upon those of slender proportions. The terms compact and slender, in this connection, have reference to the relations existing between the diameters of the cups and the lengths of the arms. Anemometers whose arms measured from the cup centers to the axis are about two, or even more times, the diameter of the cups, are considered as of slender proportions, while those whose arms similarly measured are of a length only a little greater, or even less than the diameter of the cups, are said to be of compact proportions.

A discussion of the numerical results and equations derived from the open air comparisons may be found in the *Signal Service Monthly Weather Review* for January, 1890.

The equations below are there given for the regular Signal Service anemometer, having cups 4 inches in diameter on arms 6.72 inches long:

(1) $V = .225 + 3.143v - .0362v^2$ (whirling machine);

(2) $V = .263 + 2.953v - .0407v^2$ (open air).

The velocities are in miles per hour, v being the linear velocities of the cup-centers.

Equation (2) may be considered as the equation of the Signal Service anemometer when exposed to the variable winds of the open air, while equation (1) is for the same anemometer exposed to perfectly steady winds. Quadratic equations of this form have been used by several investigators for expressing

the anemometer law. They are quite irrational, however, and wholly inadequate.

In equation (2), v becomes a maximum, for $v = \frac{2.953}{.0814}$, the interpretation of which leads to the irrational conclusion that after a certain high velocity the cups run less and less rapidly as the wind increases.

It should be noted, of course, that the constants in these equations have been computed from results at low velocities; that is, under 35 miles per hour.

Recognizing this defect of the quadratic equation, it was desired to secure a formula giving a more satisfactory extension beyond the limits of the experiments, and an equation of the following form was computed:

(3) $$\log. V = .509 + .9012v \log. v.$$

This equation is recommended for use in reducing all wind velocities observed by the Signal Service anemometer, and certain checks that have been recently obtained from wind pressure experiments, as given below, have shown the equation to be highly satisfactory.

Inasmuch as the Robinson anemometer is always constructed so that the graduations of the dials are in miles and fractions of miles, computed on the basis that the cup-centers move with a velocity $\frac{1}{3}$ that of the wind, the most convenient method of applying the above formula is by use of a table containing the observed velocity by the Robinson formula and the more accurate velocity from the formula.

The following is such a table:

Corrected Wind Velocities, as Indicated by Robinson Anemometer.

(*Miles per hour.*)

Indicated velocity.	0	1	2	3	4	5	6	7	8	9
0	......	.....	......	......	......	5.1	6.0	6.9	7.8	8.7
1	9.6	10.4	11.3	12.1	12.9	13.8	14.6	15.4	16.2	17.0
2	17.8	18.6	19.4	20.2	21.0	21.8	22.6	23.4	24.2	24.9
3	25.7	26.5	27.3	28.0	28.8	29.6	30.3	31.1	31.8	32.6
4	33.3	34.1	34.8	35.6	36.3	37.1	37.8	38.5	39.3	40.0
5	40.8	41.5	42.2	43.0	43.7	44.4	45.1	45.9	46.6	47.3
6	48.0	48.7	49.4	50.2	50.9	51.6	52.3	53.0	53.8	54.5
7	55.2	55.9	56.6	57.3	58.0	58.7	59.4	60.1	60.8	61.5
8	62.2	62.9	63.6	64.3	65.0	65.8	66.4	67.1	67.8	68.5
9	69.2	......	......	......	......	......	......	......	......	......

All observers in the United States using anemometers similar in construction to those of the Signal Service will find the values in the above table much more accurate than those commonly used.

In addition to the wind pressure experiments, several days' continuous comparisons of anemometers of different sizes were also obtained at the summit of Mount Washington, under reduced atmospheric pressure and at unusual velocities; the exposure being upon the top of the wind-pressure apparatus, to be described below.

Three anemometers, each having 4-inch cups, but with arms 4,6.7, and 7 inches long, respectively, were compared; very high velocities being obtained on one occasion, so much so, in fact, as to carry away the anemometers, all three being torn from the support at apparently the same instant, the mean velocity just previous being about 80 miles per hour.

The results of these comparisons have agreed almost perfectly with more extended and complete comparisons referred to above, though the former were over a much less range of velocity. So far as these comparisons go, I find no evidence that the Robinson anemometer is noticeably influenced by considerable changes in the atmospheric pressure. There is little reason, however, to expect that such effects, did any exist, would be apparent in comparisons of this kind.

II.—Wind Pressures.

Even at the present time of advanced experimental study of natural phenomena, our knowledge of the relations of wind pressure and velocities is very limited and incomplete. The most serious and perplexing disturbances appear to accompany investigations in this direction and accurate results have, perhaps, never been obtained. The last accounts of the experiments of Messrs. Whipple and Dines have just appeared in the September number of the *Proceedings of the Royal Society*. Notwithstanding the care exercised in conducting the experiments, the results, in some respects, are irregular and inexplicable. The method used is only possible on the basis that the pressures vary as the square of the velocity, and the success of the experiments, so far as the method is concerned, leave no doubt upon this question. The experiments made by Mr. Crosby, and given in the *Engineering News* for the latter part of June, indicated a linear law which must undoubtedly prove to be quite incorrect.

A few direct determinations of wind pressures upon large plates were made during August last at the summit of Mount Washington. The methods used, and the results obtained, are given as follows:

The apparatus was exposed upon the top of a solidly built wooden tower about 40 feet high and some 15 feet square at the top. This occupied the highest point of the mountain and afforded an unobstructed exposure for all winds from westerly and northerly directions. Southerly winds were somewhat interfered with by the presence of a low building in that direction, and the exposure for easterly winds was very bad owing to the proximity of the large hotel building. Only a very few experiments were made with southerly winds; the direction being westerly for all other experiments. No defect attributable to imperfect or unequal exposure has been discovered in the results. The diagonals of the tower were north and south and east and west, respectively. The apparatus occupied the westerly corner and was so constructed that the plate was held in front of the sides of the tower by a distance of nearly four feet. The center of the plate was, moreover, a distance of nearly six feet above the floor of tower.

The apparatus itself may be briefly described as consisting of a rigid vertical support of wrought iron pipe secured to the floor and held firmly in the corner of the railing about the tower. The anemometer was attached to a horizontal arm extending from the top of the support. The arm was adjusted to the direction of the wind and carried the anemometer in about the same vertical plane as the pressure plate, so that the wind arrived at the two at practically the same instant. The anemometer cups were about 4 feet higher than the center of the pressure plate.

The horizontal arm carrying the pressure plate consisted of a wrought iron pipe secured to the main support in such a manner that it could be revolved on a vertical axis and brought into the direction of the wind. The pressure plate was not attached directly to this arm but to a larger tube of brass, which telescoped over the iron pipe. A nicely arranged system of highly polished steel balls was provided that permitted the brass tube and pressure plate to move horizontally over the iron tube with the greatest freedom. Steel springs of varying strengths arranged to be stretched by the wind pressure were used to oppose the motion of the plate. At the rear, some five feet behind the pressure plate and attached to the main support, were the record-

ing mechanisms arranged on the ordinary chronograph principles. A sliding pencil was connected directly to an extension from the pressure plate tube and recorded the amount of distension of the spring; the zero position being constantly indicated by a line traced by a stationary pencil. A third pencil operated by an electro-magnet was in electrical connection with the anemometer, which, as before stated, was of the regular Signal Service pattern and one that had been carefully studied in connection with anemometer experiments. The electrical contacts of this anemometer were made for each 50 revolutions of the cups, a quantity that corresponds to 1-10th mile of wind movement, as computed by the Robinson formula. The chronograph cylinder revolved once in about a half hour, and was of such diameter as to give a movement of about 0.6 inch per minute.

In arranging this apparatus it was found almost impossible to automatically keep the large pressure plate with its accessories directed to the wind, so that it was necessary to secure this condition by hand and eye observation; the direction being indicated by a light cotton thread exposed above the pressure plate. I am assured that no sensible error arises from this disposition of the apparatus, as the direction of the wind, broadly considered, was very constant, being subject to only small and sudden fluctuations about a mean direction.

The records of the pressure and velocity of the wind were, therefore, automatically and simultaneously recorded on the same sheet of paper. The curve of pressures, if it can be called a curve, presents, in spite of the comparatively rapid rate of rotation of the register, a very irregular appearance indeed. The oscillations do not, except for occasional instants, correspond to harmonic vibrations of the spring and pressure plate as a vibratory system, but are actual and real changes in wind pressure. The magnitude of these variations is, itself, very irregular, but it may be stated to be approximately as much as 35 per cent. of the mean pressure. There is, in addition to these very rapid variations in the pressure which take place inside of a second or two of time, other variations which go through their irregular changes in from a few to several minutes' time.

These circumstances led me to the following method of reducing the observations: The traces on the record sheets were divided into portions representing, generally, four or five minutes of time, and during which the conditions were, to some extent, constant. The traces of the pressure were all gone over

by hand and a red ink line drawn through the pencil mark in such a manner as to get a mean curve. In this, only those variations which were of such short period that the pencil marks were too close together to distinguish were evened up. All changes of larger period were followed accurately. The next step consisted in carefully measuring the area of each subdivision, including, of course, everything between the red ink trace and the line of zero pressure. This measurement was very satisfactorily made by a small planimeter. The mean pressure is now quite accurately found by dividing the area by the length of the base of the diagram. The mean wind velocity corresponding to the same portion of the sheet is determined from the simultaneous record of the anemometer. The large number of observations obtained in this way have been grouped in sets corresponding to the velocity, and a final mean determined.

The following tables contain these results for all the experiments made:

SUMMARY OF WIND PRESSURES.

Area of plate: 9 square feet. Mean barometer: 23.9.

Velocities, in miles, per hour.			Total Pressure. Pounds.	Constants: $\frac{P}{V^2}$		
a Robinson.	b Quadratic.	c Logarithmic.		a	b	c
7.14	7.06	7.07	1.23	.0241	.0247	.0246
9.26	9.00	8.97	2.22	.0259	.0275	.0276
10.9	10.5	10.3	2.87	.0242	.0261	.0271
12.9	12.2	12.0	3.81	.0230	.0256	.0265
14.6	13.7	13.4	4.67	.0219	.0248	.0260
17.0	15.7	15.4	6.25	.0216	.0254	.0264
18.9	17.2	17.0	7.32	.0205	.0247	.0253
20.3	18.4	18.1	8.48	.0207	.0250	.0258
24.1	21.4	21.3	11.5	.0198	.0251	.0253
26.2	23.0	22.8	13.6	.0198	.9257	.0262
28.8	24.9	24.8	16.8	.0203	.0271	.0273
31.6	26.8	27.0	18.9	.0189	.0263	.0258
33.1	27.9	28.1	20.6	.0187	.0265	.0261
37.4	30.7	31.5	25.9	.0185	.0275	.0261
38.9	31.7	32.5	26.7	.0177	.0267	.0252
40.5	32.7	33.7	27.8	.0170	.0260	.0244
55.6	41.1	44.8	53.0	.0172	.0314	.0265
57.5	41.8	46.2	55.6	.0168	.0318	.0261
58.6	42.5	46.9	57.0	.0166	.0315	.0258
60.7	43.4	48.5	60.6	.0165	.0322	.0258
Means					.02567	.02600
Constant, per square foot					.00285	

SUMMARY OF WIND PRESSURES.

Area of plate: 4 square feet. Mean barometer: 23.9.

Velocities, in miles, per hour.			Total Pressure. Pounds.	Constants: $\frac{P}{V^2}$		
a Robinson.	b Quadratic.	c Logarithmic.		a	b	c
6.96	6.88	6.90	.73	.0150	.0156	.0153
8.36	8.16	8.13	1.08	.0155	.0162	.0164
10.7	10.3	10.2	1.29	.0113	.0123	.0125
13.8	13.1	12.8	2.00	.0105	.0116	.0122
14.8	13.8	13.6	2.26	.0103	.0119	.0122
17.3	16.0	15.7	3.05	.0102	.0119	.0124
18.1	16.6	16.3	3.33	.0102	.0120	.0125
21.0	18.9	18.6	3.69	.0084	.0104	.0107
23.2	20.7	20.5	5.26	.0098	.0123	.0125
25.3	22.3	22.1	5.90	.0092	.0119	.0121
26.7	23.3	23.1	6.71	.0094	.0124	.0126
29.0	25.0	24.9	7.60	.0090	.0122	.0123
31.1	26.5	26.6	8.96	.0093	.0128	.0127
32.1	27.2	27.3	8.93	.0086	.0121	.0120
34.4	28.9	29.2	9.26	.0078	.0111	.0109
43.1	34.3	35.7	13.4	.0072	.0114	.0106
44.5	35.1	36.7	15.5	.0078	.0126	.0105
46.1	36.0	37.9	15.6	.0073	.0120	.0108
48.5	37.4	39.7	20.3	.0086	.0150	.0129
51.2	39.8	41.6	19.8	.0076	.0125	.0114
52.5	40.5	42.6	22.0	.0080	.0134	.0122
54.5	41.0	44.0	22.5	.0076	.0134	.0116
56.3	41.3	45.4	23.3	.0073	.0136	.0113
58.5	42.9	46.9	21.7	.0064	.0118	.0099
Means					.01175	
Constant, per square foot					.00294	

The velocity of the wind has been computed by three different formulæ, namely, the well known Robinson formula:

$$V = 3v$$

which values appear in the first column. The second and third columns contain velocities computed respectively by the two following formulæ, already given, namely:

$$V = .263 + 2.95v - .0407v^2$$

and

$$\log. V = .509 + .9012 \log. v.$$

The last three columns of constants are computed on the assumption that the pressure of the wind varies as the square of the velocity, and correspond, respectively, to the velocities in the first three columns. It is observed that this factor is not at

all constant if velocities are taken by the Robinson formula, but that, for the quadratic equation, except for irregular variations due, it is believed, to errors of observation, the value is practically constant up to velocities between 25 and 30 miles, and that above this the values steadily increase. If the last column be considered, it appears that the values throughout are practically constant and the same as those of the upper portion of the preceding column. In a previous report upon anemometer studies, I have already expressed my conviction that velocities cannot be accurately computed by the quadratic equation for conditions higher than 30 miles per hour or thereabouts, and that the logarithmic formula was undoubtedly more accurate. These conclusions are strikingly confirmed in the wind pressure experiments here given, and I am, therefore, convinced, so far as can be determined from experiments of this kind, that the pressure of the wind varies as the square of the velocity.

If we compare the corresponding results obtained with the 9 square feet and the 4 square feet plates, we find further that the pressure varies strictly in proportion to the area of the plate. A critical examination of the constants in the case of the 4 square feet plate shows greater irregularity than that for the 9 square feet plate. It should be noticed in this connection that a much greater number of observations were made with the 9 square feet than the 4 square feet plate; moreover, the first two and the last observation with the 4 square feet plate have been queried as they do not agree well with the other results. Some explanation of this is found in the fact that they are results of single observations only, while nearly all the other values are the mean of several observations.

It remains now to say that the mean barometric pressure during my experiments was 23.9, and that the final value of the constant, namely, .0029, needs to be slightly altered in order to reduce to the condition of normal action of the wind. The actual direction of the wind, as before mentioned, was inclined upwards, and this I found was also practically a constant quantity, particularly so as nearly all my experiments were made with the wind in one direction. The amount of this inclination, as nearly as it could be determined, may be taken at about 15°. We do not, perhaps, know very well the law of variation of pressure with angle of inclination, but I am disposed to increase the above factor in proportion to the cos^2 of the angle of inclination, which gives .0032. I will assume further that the wind

pressure is proportional to the density of the air; therefore, the factor reduced to 30 inches barometric pressure becomes .0040, and the formula for computing wind pressure under barometric pressures of 30 inches may be expressed as follows:

$$P = .0040 V^2 S$$

where V is wind velocity in miles per hour, P is the pressure in pounds per square foot, and S is the area of the plate.

This formula being determined by direct comparison of the anemometer and pressure plate, can always be used whenever the velocity is measured by the Robinson anemometer. The coefficient .0040 differs from a generally accepted value, namely: .005, and from the value .0029, found by Messrs. Whipple and Dines by about the same amount, being between the two.

For engineering purposes this formula gives very closely, I think, the actual pressures corresponding to velocities computed by the logarithmic formula, as applied to the Robinson anemometer, and this is the instrument almost universally used for measuring wind movements. Where the Robinson anemometer, having its dials graduated to read miles, is used, the observed velocity can easily be reduced to the true velocity by the use of the table already given.

In estimating the strains to which engineering structures may be subjected by winds, the maximum pressures are, of course, the most important. The above formula gives a mean pressure corresponding to a mean wind velocity. It is important to note that momentary pressures as much as 35 per cent in excess of the above mean pressure may continually occur and recur. If their rate of occurrence be at all synchronous with a natural time of vibration of the structure or any part thereof, remarkable effects may follow.

RECENT SAVING OF LIFE IN MICHIGAN.

Dr. Baker gives official statistics and evidence which he summarized as follows: "It is a record of the saving of over one hundred lives per year from small-pox, four hundred from scarlet fever, and nearly six hundred from diphtheria—an aggregate of eleven hundred lives per year, or three lives per day saved from these three diseases! This is a record which we ask to have examined, and which we are willing to have compared with that of the man who 'made two blades of grass grow where only one grew before.'"

METEOROLOGICAL OBSERVATIONS TAKEN IN FOUR BALLOON VOYAGES.

BY W. H. HAMMON,
Sergeant in the Signal Corps, U. S. A.

Read at the meeting of the Amer. Assoc. Adv. Sci. and now communicated by permission of the Chief Signal Officer.

PREPARATIONS FOR OBSERVATIONS.

(1) The instructions in regard to the kind of observations, and the manner of taking them, were given by Professor Cleveland Abbe; the investigations of corrections to the aneroids and the thermometers were made under the instructions of Professor Thomas Russell, in charge of comparisons. The schedule of observation was the same for each ascension, and required, principally, readings of wet and dry bulb thermometers, and of the barometer. The observations were to be made as frequently as possible.

The instruments furnished for the purpose of taking observations were as follows:

2 aneroid barometers,
2 psychrometers (arranged for whirling),
1 maximum thermometer,
1 minimum thermometer,
1 watch, set to 75th meridian time.

Besides these instruments, there were carried a compass, a Davy's safety lamp, a pair of field glasses and minor articles. The maximum thermometer was carried only on the first ascension. The minimum thermometer was broken on the second voyage and was not used on the succeeding ascensions. The safety lamp was not procured until after the first ascension.

NOTE BY PROFESSOR ABBE.—During the first fourteen years of its meteorological work, the Signal Office on several occasions, profited by several generous offers of the well-known æronaut, Professor S. A. King, of Philadelphia, and was thus able, at an insignificant expense, to send its observers, with proper instruments, into the upper regions of the atmosphere. It was, however, evident that such ascensions, made at times to suit the convenience of others rather than meteorologists, needed to be supplemented by special ascents, wholly within the control of the Signal Office. In the autumn of 1884, an arrangement was made [by the late General Wm. B. Hazen] with Professor King, by which he contributed, gratuitously, his own services and the use of his balloon, while the Signal Office paid the necessary expenses incidental to each ascent; most important of all, Pro-

(2) The aneroid barometer used was from J. W. Queen & Co., of Philadelphia: Its dial is five inches in diameter and is graduated to .05 in. The graduation extends from 31 to 15 inches. It has been given the number "S. S. 190." The corrections for the aneroid were determined by Professor Thomas Russell on December 27 and 29, 1884. It was placed in a large receiver to an air-pump with a mercurial barometer and the pressure reduced to 16 inches and readings taken as the pressure increased. Table 1 gives the corrections obtained.

TABLE I.—*Aneroid, S. S. 190.*

Scale reading.	December 27, 1884. Temperature, 30 F.	December 29, 1884. Temperature, 60 F.
inches.	inches.	inches.
30.5	+0.25	+0.23
30.0	+0.22	+0.16
28.0	+0.21	+0.19
26.0	+0.24	+0.23
24.0	+0.18	+0.18
22.0	+0.07	+0.11
20.0	+0.02	+0.10
18.0	+0.04	+0.14
16.0	−0.01	+0.09

This operation was repeated after returning from the second, third and fourth ascensions. The resulting corrections are given in table II.

These corrections were all obtained with increasing pressures after the instrument had been subjected to a low pressure corresponding to the lowest scale reading observed during the voy-

fessor King agreed to start whenever ordered by telegraph, no matter what the state of the weather might be.

Under this arrangement, four meteorological ascensions were made in January, March and April, 1885. In each case the same observer, Private W. H. Hammon, volunteered and to his enthusiasm, faithfulness and skill, we are indebted for observations that, as shown by the accompanying report, are undoubtedly entitled to be ranked among the best hitherto obtained. In each case, the observer was ordered to proceed directly from Washington to Philadelphia as soon as I reported that the preceding weather map indicated meteorological conditions of sufficient interest to warrant the ascent: Professor King was at the same time ordered by telegraph, to prepare for an immediate ascent upon the arrival of the observer. As the observations made by Private Hammon were intended to elucidate points in

TABLE II.—*Aneroid, S. S. 190.*

Scale reading.	March 21, 1885 Temperature, 75 F	April 3, 1885. Temperature, 70 F.	April 18, 1885. Temp. 66 F.
inches.	inches.	inches.	inches.
30.5			
30.0	+0.09	+0.12	+0.09
29.0	+0.11	+0.14	+0.05
28.0	+0.08	+0.14	+0.05
27.0	+0.07	+0.12	+0.07
26.0	+0.06	+0.15	+0.06
25.5	+0.01		+0.02
25.0		+0.09	
24.0		+0.05	
23.0		−0.04	

age. Owing to the sluggish action of the aneroid, the readings, while it is falling should have their corrections changed by a quantity, varying, with the change in pressure, from 0.0 to 0.1 of an inch. Since under similar conditions, the corrections are very nearly constant for all pressures, a uniform correction of 0.05 in. was applied by me to all readings taken during the present balloon voyages.

(3) The psychrometer used during the first voyage was made of two signal service exposed thermometers with spherical bulbs and graduated on the glass stems. These thermometers were made by H. J. Green & Co., of New York. The bulbs were

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connection with the state of the atmosphere, on the respective days, they are to be considered as giving data, additional to the data given on the weather maps of the same dates. The published folio weather maps for 3 P. M. on each of the four dates, will show the meteorological conditions prevailing during the ascents. In each of these ascensions Professor King was ordered to make the voyage last as long as possible, the agreement being that if very high ascents were ordered, they could not possibly be of long duration, and it was considered important, in the present series, to gain experience by voyages at moderate elevations. On account of the nearness of the starting point to the ocean, it must frequently happen, as in the first of the present series of voyages, that a short voyage, from this point, with a west wind, will bring the æronaut to the shore of the ocean. It is therefore desirable that future voyages be made from some point in the interior, and instead of always starting from the same point, under appropriate meteorological conditions, it would be better to make successive ascents, as rapidly as possible, during a month or more.

September, 1885.

eleven m. m. in diameter and the graduation of the stem to single degrees Fahrenheit. Both thermometers were attached firmly to a brass back; the bulb of the wet thermometer extending about an inch below that of the dry. The wet bulb was covered with very thin muslin fitted very neatly to it. This was kept moistened by frequent immersions in a bottle of water. The bulb was usually moistened immediately after an observation was taken, so that the thermometer would assume very nearly its proper temperature before the next observation was begun. A strong cord was attached to the psychrometer for whirling, according to De Saussure's manner of using the sling thermometer. Below is given a table of corrections for scale error as determined at the signal office:

TABLE III.

Scale Reading	Dry Bulb No. 1084	Wet Bulb No. 1476
+2°	—0°.6	0°.0
12	—0.2	0.0
22	0.0	—0.1
32	0.0	—0.2
42	+0.1	0.0
52	0.0	0.0
62	0.0	—0.1
72	0.0	—0.2

The psychrometer used on the succeeding voyages was made of two of Green's delicate cylindrical-bulb, stem-graduated thermometers, with open scale and graduated to single degree. The bulbs were four and a half m. m. in diameter and fifteen m. m. in length. They were attached to a small wooden back, and, provided with a strong cord, were arranged for whirling in the same manner as the other. The corrections for scale error of these thermometers, as determined at the signal office, are given below:

TABLE IV.

Scale Reading	Dry Bulb No. 6677	Wet Bulb No. 6673
+2°	—0°.9	—0°.5
+12	—0.8	—0.4
+22	.....	.....
32	—0.25	—0.2
42	—0.25	—0.3
52	—0.3	—0.3
62	—0.35	—0.35
72	—0.2	—0.2
82	—0.15	—0.3

The wooden or brass backing for each psychrometer was a narrow strip which ended fully an inch above the bulbs of the thermometers, so that it could in no manner be a cause of error in the thermometer readings.

(4) The question of the sensitiveness of these thermometers has been studied according to the method given in Dr. M. Thiesen's article "Vergleichungen von Quicksilberthermometern" in Metronomische Beitrage No. 3, Berlin, 1881.

By sensitiveness is meant the rapidity with which a thermometer will assume the temperature of any bath in which it is placed. The following is Thiesen's description of the method used:

When a thermometer changes its temperature, by convection processes, it is assumed that the rate of change is approximately proportional to the difference between its temperature and that of the medium in which it is placed, whence there follows the equation.

(1) $$\frac{dv}{dt} = \lambda\,(u - v),$$

in which,

v, is the temperature of the thermometer;
u, is the temperature of the medium;
λ, is a constant depending on the sensitiveness of the thermometer;
t, is the time.

This formula also holds good approximately for small differences of $u - v$, when the effect of radiation is considered, the thermometers being in a bath of gas instead of liquid.

If λ is considered known, and the temperature of the medium is varying (as was the case during the ascensions) then, if the rate of variation, v, is observed for any moment, the approximate temperature of the medium, at any particular time, can be obtained from the thermometer reading, by the following equation:

(2) $$u = v + \frac{1}{\lambda}\,\frac{dv}{dt}$$

To determine λ for any special thermometer, let its initial temperature be V at the time $t = o$, when it is put into a medium of constant temperature U. In this case the integral of (1) becomes

(3) $$Mod.\ \lambda\, t = \log\frac{U - V}{U - v} = \log\frac{V - U}{v - U}.$$

in which, *Mod.* is the modulus of the system of common logarithms and is equal to 0.4343.

The observations consist in following the variation of the thermometer and noting the times (t) of successive readings (v). After a considerable time has elapsed, the last reading of the thermometer will be very nearly, the temperature of the medium, or U.

For the purpose of ascertaining how well this equation satisfies the observations, the latter were graphically plotted, the times (t) being the abscissas and $\log(v - U)$ the ordinates. Assuming the last term to be the variable, the equation is that of a straight line and, if it correctly represents the observations, they should plot into such a line, or at least should be convertible into such by improving the value of U within the limits of probable error in its determination.

The tangent of the angle made by the line with the axis of X is equal *mod.* λ. In reality, the curves for different thermometers and the values $V - U$ are merely approximations to straight lines, yet in spite of these deviations, tolerable good values of $1 \div \lambda$ can be obtained, and the graphical solution converted into a numerical one. Let two points on the curve, wide apart, be selected, which may be regarded as especially characteristic of the curve; then, from the observations near these two points compute by equation (3) the value of $1 \div \lambda$. Two points should be chosen, so that when a straight line is drawn through them, there will be equal areas on both sides of the straight line between it and the curve.

The following is an example of my application of Thiesen's the process as just described. Thermometer No. 1084 was placed in a bath of mercury and raised to a temperature of 111° F. and then placed in a glass tube, through which was blown a current of air, of constant temperature, and at a uniform velocity of about twelve feet per second.* The length of time that it took the column to fall past regular intervals, on the scale was registered on the chronograph, as given in the following table and was plotted as a diagram:

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* In all previous work on the sensitiveness of thermometers the convection current that was supposed to keep the surface of the bulb at a constant temperature has been simply the natural current due to the difference of temperature of the bulb and air (Gylden & Abbe, 1886.) or the bulb and water or melting ice (Thiesen, 1883); but Thiesen's method implies a thoroughly constant temperature of the surface of the bulb as really exists in the whirled psychrometer and this was attained by the convection tube of Hammon & Russell. C. A.

TABLE V.

Thermometer No. 1084.

(v).	(t).	(v — U).	log. (v — U).
100° F.	0.0 Sec.	19.3° F.	1.286
95	17.7	14.3	1.155
90	42.7	9.3	0.968
89	49.5	8.3	.919
88	56.9	7.3	.863
87	65.4	6.3	.799
86	75.9	5.3	.724
85	88.6	4.3	.633
84	101.7	3.3	.519
83	121.7	2.3	.362
82	152.3	1.3	.114

$U = 80.7°$ F.

Inspection shows that the observations at 42.7 sec. and 152.3 sec. are the best to be selected for computing $1 \div \lambda$. Applying equation (3) to these two observations, there results $1 \div \lambda = 55.7$ sec.

Table VI gives two similar series of observations on thermometer No. 1476.

TABLE VI.

Thermometer No. 1476.

First series.		Second series.	
(v).	(t).	(v).	(t).
105° F.	0.0 Sec.	100° F.	0.0 Sec.
100	9.2	95	18.3
95	21.1	90	45.2
90	36.5	89	53.4
85	59.3	88	63.4
84	64.7	87	74.5
83	72.1	86	86.9
82	80.3	85	104.4
81	91.1	84	131.6
80	100.9	83	180.7
79	117.4		
78	138.1		
77	177.0		
$U = 76.6°$ F. $\frac{1}{\lambda} = 53.6$ seconds		$U = 82.6°$ F. $\frac{1}{\lambda} = 50.7$ seconds	

Mean value — $\frac{1}{\lambda} = 52.2$.

In determining the sensitiveness of a thermometer with a cylindrical tube, a hole was blown through the side of a glass tube through which the bulb was insertod into the tube, and by this means it was arranged so that the current of air was blown past the sides of the bulb, producing a similar ventilation to that when the thermometer is whirled. The cylindrical bulb thermometers, Nos. 6,673 and 6,677, used on the last three ascensions, were broken previous to these experiments, but the values of $1 \div \lambda$ were determined with considerable accuracy in the following manner: A number of thermometers, among which were these two, had been experimented upon in order to ascertain their relative sensitiveness in water. They were taken in succession from a bath of water of a temperature of 40° F., and immersed in one of about 97°, and the time it took the mercury in each thermometer to rise from 70° to 90° was noted by means of the chronograph. These observations are given in Table VII, together with those of hygrometer tubes Nos. 1,109 and 734.

TABLE VII.

Time required by mercurial column to rise from 70° to 90° F.

No. 1,109	No. 744.	No. 6,673.	No. 6,677.
1.31 Sec.	1.45 Sec.	1.8 Sec.	1.45 Sec.
1.31	1.43	1.8	1.5
1.18	1.49	1.5	1.65
1.27	1.53	1.5	1.65
1.27	1.53	1.55	1.6
1.23	1.39	1.47	1.5
1.21	1.43	1.5	1.6
1.23	1.51	1.5	1.53
1.21	1.51	1.5	....
1.31	1.47	1.5	....
1.27	1.55	1.5	....
1.41	1.53	1.8	....
1.31	....	1.6	....
1.47	....	1.5	....
....	....	1.53	....
....	....	1.53	....
....	....	1.53	....
1.28	1.49	1.57	1.56

In Table VIII are given observations of 1,109 and 724 in air, made as above described.

TABLE VIII.

Hygrometer Tube No. 1,109.				Hygro. Tube No. 734.	
First Series.		Second Series.			
(v)	(t)	(v)	(t)	(v)	(t)
90° F.	0.0 sec	90°	0.0 sec	85°	0.0 sec
85	5.6	85	3.7	80	6.1
80	12.2	80	8.3	75	15.7
75	22.2	75	15.3	70	28.4
70	40.7	70	24.6	69	32.1
68	61.4	65	45.0	68	36.4
67	78.3	64	51.3	67	42.8
..	....	63	60.6	66	49.4
..	....	62	78.0	65	57.5
..	....	..	....	64	70.8
..	....	..	....	63	90.3
$U = 65°.0$ F.		$U = 61°.3$ F.		$U = 61.8$ F.	
$1 \div \lambda = 25.4$ sec.		$1 \div \lambda = 27.1$ sec.		$1 \div \lambda = 30.6$ sec.	

Mean valve of $1 \div \lambda$ for No. 1109 = 26.2 sec.

From a comparison of the observations of 1109 and 734 in water and in air, it can be seen that the periods of time that it took the thermometers to pass from 70° to 90° F. in water are almost exactly proportional to the values of $1 \div \lambda$ found in air. This indicates that, for different thermometers, very nearly the same ratio exists between the values of $1 \div \lambda$ obtained from readings in water as obtained from readings in air. From this proportion the following values of $1 \div \lambda$ in air are obtained:

TABLE IX.

Thermometer.	$\frac{1}{\lambda}$
6,673	32.2
6,677	32.0

These experiments show that the thermometers used on the first ascension, when heated 5° above the temperature of the air, return to within 0.5° of their former readings in a little less than two minutes, and those used on the succeeding ascensions in one minute and seventeen seconds.

(5) The car of the balloon was a wicker-work basket about three feet six inches long, by two feet nine inches wide, and two feet three inches deep. The car was suspended about six and a half feet from the hoop. At the top of the car were suspended the aneroid barometer and the watch, while the sling-psychro-

meter was hung outside the car when not in use. The order of operations was:

First: Time noted.

Second: Barometer raised to a horizontal position, tapped wlth the hand, read and recorded.

Third. Psychrometer whirled outside the car for about two minutes on the first ascent, and one minute on the succeeding ones, thermometers then read and recorded.

Fourth: Barometer read and recorded in the same manner as above.

Fifth: Time noted.

Below is given the average time consumed in taking such a series of observations.

TABLE X.

Series of Operations Performed.	1st. Ascent.		2nd, 3d and 4th Ascents.	
	Min.	Sec.	Min.	Sec.
Noting time, reading and recording barometer	0	40	0	35
Whirling and reading thermometers..........	2	00	1	15
Recording thermometer readings, reading and recording barometer and noting time........	0	50	0	45
Total time for the whole series............	3	30	2	25

On account of the greater sensitiveness, it was unnecessary to whirl the thermometers used on the last ascensions as long as those used on the first in order to obtain the same correctness of temperature.

DESCRIPTION OF ASCENTS AND GENERAL OBSERVATIONS.

(6) The ascensions were all made from the ground of Girard College, Philadelphia, Pennsylvania, with Professor S. A. King, as aeronaut, in his balloon called the "Eagle Eyrie." The capacity of the balloon is 25,000 cubic feet, and it was filled with common illuminating gas from the city gas mains.

First Ascent, January 19,1885. For two days previons to the ascension, the barometer had been rapidly rising, and a strong northwest wind blowing. On the nineteenth, the temperature was very low over the entire country east of the Mississippi; the meau temperature at Philadelphia for the day was 21° Fahrenheit. The barometer at Philadelphia was one half inch above the normal height, and almost as high as at any other place in the United States. With the exception of a slight haze the sky was clear. It was intended that the ascent be

made as early as possible on the morning of the 19th, and for that purpose the balloon was spread out on the ground the evening before, and all preparations were made that evening for the inflation early next morning; but, on account of the cold rendering the material of the balloon envelope brittle, the filling could not be commenced until noon, when the sun's heat had rendered the envelope sufficiently pliable. The filling having been completed, the ascent occurred at 4:12 P. M.

At the ground, and up to an altitude of about 3,000 feet, the wind blew from the northwest, but above that elevation, the wind was from the southwest, as indicated by the path of the balloon. While passing through the northwest current, the temperature fell at the rate of one degree for every change in elevation of 220 feet. The balloon rose only about 1,800 feet higher while in the southwest corrent. At this height, the temperature had risen four degrees, and again on descending to the northwest current, there was a corresponding decrease of temperature. Shortly after five o'clock the balloon approached an extensive forest, and Professor King deemed it advisable to check the ascent of the balloon and save the ballast in case it might be needed to carry us over the forest to a suitable place for landing; otherwise a much higher altitude could have been attained.

At 5:40 P. M. it became too dark to take further readings of the instruments. The orders of the Chief Signal Officer having contemplated only an early start and daylight voyage, no light for night observations had been provided. A safe landing was effected at Manahawken, N. J., at 7:05 P. M., after having traversed a distance of about sixty miles in two hours and fifty minutes.

The highest altitude attained during the voyage was 4,800 feet at 5:00 P. M. The lowest temperature observed, 8:7 F. was at a height of about 2,700 feet. What appeared most remarkable was the extreme dryness of the atmosphere at the highest altitudes. On the ground, at the beginning of the voyage, the dew-point was 21:5 degrees below the temperature of the air, and the relative humidity 37.7 per cent.; while at the highest altitude, the dew-point was 40 degrees lower than the temperature of the air, and the relative humidity 13.6 per cent.

Attention is also called to the fact that the depth of the cold northwest current accompanying a severe cold wave was but 3,000 feet.

Second Ascent, March 13, 1885.—On the day preceding this ascension the weather was generally cloudy and the wind in the vicinity of Philadelphia was variable. An area of low barometer was developing in the Mississippi valley preceded by rainy weather, while an area of high barometer extended over Canada. On the morning of the ascent, the area of high barometer had forced itself southward, accompanied by a cold wave, while the barometer was lowest on the Carolina coast. The temperature had fallen about twenty degrees during the night. The weather was cloudy, the clouds being low and sometimes so thin that the sun's disc could be seen dimly through them. The wind was blowing steadily from the northeast at a rate of about fifteen miles an hour.

The ascent began at 1:38 P. M., the balloon rising rapidly and entering the clouds in four and a half minutes, at an elevation of a little less than 2,000 feet. At this time we were moving in a south-westerly direction. The upper surface of the cloud was reached in ten minutes more, at an elevation of 2,800 feet. Scattered in the sky above were cumulo-stratus clouds, which moved away rapidly toward the southeast. At 1:59 P. M. we were in clear warm sunshine. At 2:10 P. M. we saw the earth dimly through the clouds and ascertained we were moving toward the northwest. The clouds beneath us were moving in the same direction, but much more rapidly. The balloon rose more rapidly as it became heated by the sun, and at 2:20 P. M. we had reached a height of 4,350 feet, the highest altitude attained during the voyage. In a few minutes the sky became more hazy and the balloon began to descend. The descent was rapid, although ballast was constantly let out. At 2:36 P. M. we entered the clouds from above, at an elevation of 3,200 feet and reached the lower edge at an elevation of over 2,400 feet in two minutes. In a few minutes the drag rope touched the ground, when we found we were on the west bank of the Schuylkill river about sixteen miles northwest of Philadelphia. For a few minutes the balloon moved along near the ground, the drag rope touching. Professor King continued to let out sand and at 2:54 P. M. the balloon again began to ascend. At a height of 2,400 feet we again entered the clouds, which seemed to be composed of minute particles of ice, but so small that their exact form could not be distinguished with the naked eye. We were in the clouds nearly twenty minutes, and when above them we found the sky overcast by dense stratus clouds. As the descent

began, the clouds seemed to break away from about us, or we seemed to continue just in the edge of the cloud while we descended about 500 feet. We passed out of the cloud at 3:55 P. M. at an altitude of 2,300 feet. We were then over a hilly country about two miles west of the Schuylkill river, and near the line between Chester and Berks counties, Pennsylvania. After passing over two or three hills we landed in Union township, Berks County, Pa., at 4:12 P. M.

The temperature on the ground at starting was 24.3° F., and on landing it was 22.5° F. The lowest temperature observed in each ascent and descent was at or near the lowest edge of the cloud. The average temperature at that elevation was about 15° F. The temperature gradually rose as we ascended through the cloud, it being about five degrees warmer at the top than at the lower edge. For the 1,500 feet of the ascent above the cloud, the changes of temperature were rapid and irregular, but indicating an average rise of temperature of one degree for an increase in altitude of 300 feet, up to the highest altitude attained. Attention is called to the fact, that, while in the cloud, the wet-bulb thermometer continually read higher than the dry-bulb, by about three-tenths of a degree. This could not have been due to the coating of ice making thermometer less sensitive, because the difference did not diminish with longer exposure, and continued when the temperature was rising as well as when it was falling.

Third Ascent, March 27, 1885.—On the day of the ascension the barometer was lowest in the St. Lawrence valley. The winds were generally south-westerly and very light, not exceeding six miles per hour at Philadelphia or New York during the day. The weather was cloudless at Philadelphia in the morning, but the sky became overcast with high stratus clouds during the forenoon. A light haze prevailed and a light rain fell between three and four o'clock in the afternoon, followed by heavier rain later in the evening. The ascent began at 12:27 P. M., the balloon rising steadily until 2:00 P. M., when it had reached a height of 6,200 feet, the highest altitude of the voyage. At the height of 2,000 feet the balloon entered a stratum of haze which continued to envelope it, even until the end of the voyage. The temperature fell steadily as we ascended. On the ground at starting it was 51.1° F.; at a height of 3,000 feet it was 46°, and at the highest altitude 34.6°. During the voyage the balloon moved in almost a direct line towards the north-east. At 1:11

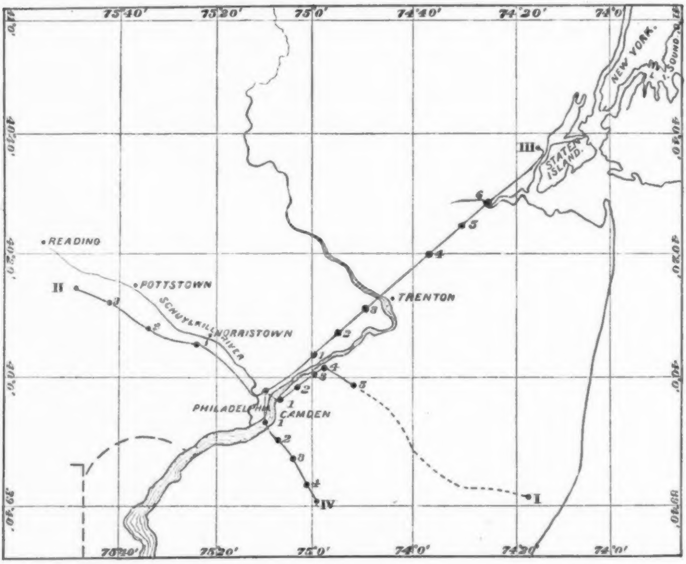
P. M. it passed over Trenton, N. J.; at 1:31 P. M., Princeton was passed; at 1:46 P. M. it was opposite New Brunswick and about two miles east of that city. At 2:10 P. M. we were about one mile west of Staten Island Sound and two miles from the head of Raritan Bay, at which time it was deemed advisable to descend because of the danger of being blown out to sea. A safe landing was made near Tremly, N. J. at 2:19 P. M., having traversed a distance of about seventy miles in one hour and fifty-two minutes; while on the ground the wind was not more than five miles an hour.

Fourth Ascent, April 16, 1885.—On the day preceding the ascension, the barometer was lowest in Kansas and Missouri. Cloudy weather prevailed during the evening and night and a light rain fell; but the weather was clear in the morning. On the day of the ascension the sky was cloudless; the wind from the north-west, and blowing at a velocity of fifteen miles per hour.

The ascent was begun at 12:31 P. M., the balloon rising rapidly and reaching an elevation of 3,000 feet in seven minutes. After that it rose slowly, until at one o'clock the highest altitude, 4,300 feet, was attained. From this elevation we descended slowly until, from 1:30 to 1:40 P. M. we were less than 1,000 feet high. Afterward, the balloon again rose to an altitude of 3,000 feet. At 2:00 P. M., it was approaching an extensive forest in Central New Jersey, and being nearly out of ballast, we decided to descend. When we had descended (by letting out gas) to within 500 or 600 feet of the ground, the balloon suddenly rose fully 500 feet without any perceptible cause, and again on opening the valve, it fell rapidly to the ground, striking with a severe jar. Although there had been but a very slight wind at the height at which we had been traveling; as we approached the earth its velocity increased, and, after striking the ground the first time, the balloon rebounded and was driven by the wind for at least half a mile, striking the ground repeatedly and rebounding to a height of more than one hundred feet. At last the anchor caught, and with the assistance of several persons, a landing was made near Williamstown, N. J., at 2:20 P. M., having gone a distance of twenty-three miles in two hours and seven minutes. The shocks experienced in landing were sufficient to break the thermometers.

The temperature, at starting, was 50.5°, and 55.3° on landing. The lowest temperature, 31.0°, was observed at elevation of 4,150

feet, it being 1.7° degrees lower than at the highest elevation reached. During the entire voyage gusts of wind were frequently observed blowing from different directions. Frequently the currents seemed to be blowing upwards when the balloon was nearly stationary. The accompanying map shows the direction taken.



(7) *Meteorological Observations.*—The meteorological observations taken during the ascents are contained in tables XI, XII, XIII and XIV, the observations for each ascent being given in a separate table.

Column 1 contains the time observed at the beginning of each of the series of observations recorded on the respective lines.

Column 2 contains the barometer reading observed before whirling and reading the thermometers.

Columns 3 and 4, respectively, contain the readings of the dry and wet-bulb thermometers, after whirling and corrected for scale error according to the S. S. correction cards.

Column 5 contains the barometer readings observed immediately after the readings of the thermometers.

Column 6 contains the time observed at the end of each series of observations. The barometer readings here given have been corrected by .05 in. The readings of the barometer were made to .01 in., but, on account of the imperfections of the instrument (see section 2, pages 5 and 6) the readings cannot be relied upon to give the correct pressure of the air nearer than 0.1 in.

Column 7 contains the means of the times in column 1 and 6, and column 8 the means of the barometer readings in columns 2 and 5. The times in column 7 are considered as very close approximations to the times for which the mean pressures in column 8 and the temperatures in 3 and 4 hold good. The average change in temperature between each observation was 1.8°, and the average time between observations was about five minutes. The average rate of ventilation was approximately the same as that at which the experiments for sensitiveness were made (see section 4). Consequently the temperature, as indicated by the thermometer, at the time of any observation, was that of the air to which it was exposed at an earlier time, differing by not more than eight seconds on the first ascension, and five seconds on the succeeding ones, from the mean time adopted. This slight difference in time would make no appreciable error in the readings. The greatest error, in any of the observations, because of this approximation, is, with but one or two exceptions, not greater than 0.3°, and the average error is much less than 0.1°. The correction, therefore, has been omitted, and the temperatures in 3 and 4 are assumed to be the temperatures corresponding to the times in 7 as above stated. Column 9 contains the altitudes corresponding to the mean barometer readings. They were computed by the formula and tables found in Professor William Ferrel's paper on Barometric Hypsometry, published by the U. S. Coast Survey.

Column 10 contains the vapor tensions as computed by the formula,

$$x = f - .00065\ (t - t')\ \frac{5}{9}\ h,$$

in which,

x = the elastic force of aqueous vapor in inches, which exists in the air at the time of the observation.

f = Regnault's value, in inches, of the tension of aqueous vapor, in saturated air at a temperature, corresponding to the reading of the wet-bulb thermometer.

$(t - t')$ = difference, in degrees, Fahrenheit, between wet and dry bulb thermometers.

h = height of barometer, in inches.

The constant, .00065 is Sworykin's value, and is recommended by Professor Ferrel, for ice and for water, for the degree of ventilation used in the observations.

Column 11 contains the corresponding dew-points, as obtained from Regnault's tables of vapor tension.

Column 12 contains the percentage of relative humidity. The numbers in the column of notes marked thus (.) refer to places marked on the accompanying maps, indicating the position of points directly beneath the balloon. The observations, referred to above, are, in part presented graphically on diagrams I, II, III, and IV, which show the vertical path of the balloon on the different ascents, the ordinates being the altitudes and the abscissas the times. On each curve are marked the places at which the observations were made, also readings of the dry and wet-bulb thermometers. The dotted curve in diagram No. 1 shows the probable path during the night time.

(See Tables XI, XII, XIII, XIV, and Diagrams 1, 2, 3, 4.)

(8) *Horizontal Direction and Velocity of Balloon.*—Table XV, contains the velocities of the currents of air at different elevations. These were obtained in the following manner: Whenever it was possible to locate, with considerable accuracy, the position of the balloon over the earth, a dot was entered on the accompanying map, and a record made of the time at which the point was located. The velocity of the current of air in which the balloon was floating at the time, was directly determined by measuring the distance between these dots and the length of time consumed in traveling over the distance between them. These points were located by observing the bearing of certain well defined objects on the earth's surface, in the immediate vicinity of the observer, and which could be easily recognized on the map. The scale of the map used on the first, third and fourth ascensions was five miles to the inch. These voyages were made over densely populated districts, containing many objects, easily recognized, and the points on the map were located with a much greater degree of accuracy than could have been done had the country been less settled. The probable error in locating these points on the map, was certainly not greater than 0.5 of a mile. From this the probable error in velocity of the air currents, is obtained by the following formula:

$$x = \pm\frac{60}{a} \times 0.5\sqrt{2}\,.$$

TABLE XI.—*Observations taken during the first ascension made on January 19, 1885, from Girard College, Philadelphia, Pa.*

Observations.						Results.						
Time, 75th Mer.	Cor. Bar. Reading.	Temperatures. Dry Bulb.	Temperatures. Wet Bulb.	Cor. Bar. Reading.	Time, 75th Mer.	Mean Time, 75th Mer.	Mean Bar. Reading.	Altitude.	Vapor Tension.	Dew Point.	Relative Humidity.	Remarks.
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In.	°F.	p. ct.	
3:55	30.27	23.5	18.6	......	......	......	......	100	·0475	+ 2.0	37.7	On ground at Girard College, Phila.
4:12	......	......	......	......	......	......	......	......	......	......	......	Started.
4:18	27.85	9.8	6.5	26.50	4:21	4:19.5	27.18	2847	.0257	—11.0	38.1	
4:22	26.10	......	......	......	......	......	......	......	......	......	......	Located Station No. 1 on chart.
4:26	25.80	11.8	7.5	25.90	4.30	4:28	25.85	4144	.0204	—15.5	27.7	
4:30	......	......	......	......	......	......	......	......	......	......	......	Let out sand.
4:32	25.68	12.5	7.3	25.35	4:35	4:33.5	25.52	4476	.0165	—19.5	21.6	
*4:36	25.23	......	......	......	......	......	......	......	......	......	......	No. 2 located.
4:51	25.65	11.8	7.0	25.23	4.55	4:53	25.44	4567	.0147	—22.0	19.9	
4:58	25.35	......	......	......	......	......	......	......	......	......	......	No. 3 located.
5:05	25.33	......	......	......	......	......	......	......	......	......	......	No. 4. Bar index stuck and failed to move until severely jarred.
5:07	25.23	12.8	7.7	25.33	5:11	5:09	25.28	4749	.0105	—28.0	13.6	Let out sand.
5:14	25.50	......	......	......	......	......	......	......	......	......	......	No. 5. Ascent checked because about to pass over extensive forests and all buoyancy might be needed to cross them.
5:17	26.13	12.3	7.3	26.05	5:20	5:18.5	26.09	3941	.0127	—24.5	16.8	
5:25	26.45	......	......	......	......	......	......	......	......	......	......	At 5:25 heard voice from the ground.
5:29	26.65	......	......	......	......	......	......	......	......	......	......	
5:31	26.50	......	......	......	......	......	......	......	......	......	......	Sudden rise without perceptible cause.
5:32	26.40	8.7	6.3	27.05	5:36	5:34	26.72	3319	.0352	— 4.3	54.6	
5:39	26.75	......	......	......	......	......	......	......	......	......	......	After 5:39 P. M. too dark to read instruments.
7:05	......	......	......	......	......	......	......	......	......	......	......	Landed at Manahaw-ken, N. J.
7:25	30.37	21.1	18.0	......	......	......	......	......	.0645	+ 8.5	57.1	On ground at Manahaw-ken, N. J.

*——Delay from 4.36 to 4:51 caused by assisting Prof. King.

TABLE XII.—*Observations taken during the second ascension made March 13, 1885, from Girard College Grounds, Philadelphia, Pa.*

Observations.						Results.						
Time. 15th Mer.	Cor. Bar. Reading.	Temperature. Dry Bulb.	Temperature. Wet Bulb.	Cor. Bar. Reading.	Time. 75th Mer.	Mean Time. 75th Mer.	Mean Bar. Reading.	Altitude.	Vapor Tension.	Dew Point.	Relative Humidity.	Remarks.
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In.	°F.	P. C.	
1:17	29.98	24.3	21.8					100	.0893	15.9	68.2	On ground, Girard College, Phila., Pa.
1:38												Started.
1:38	29.98	22.7	20.4	29.25	1:41	1:39.5	29.62	555	.0845	14.7	69.3	
1:42.5												Enter cloud.
1:42.5	28.10	16.4	16.2	27.55	1:44.5	1:43.5	27.83	2155	.0888	15.8	97.2	
1:45.5	27.55	*18.3	*18.3	27.48	1:47	1:46	27.52	2441	.0998	18.3	100.0	* Possible error in record. Min. therm. read 17.3.
1:49												
1:50	27.15	20.7	20.9	27.18	1:53	1:51.5	27.16	2780	.1113	20.7	100.0	
1:53												Upper surface of cloud: sky above partly covered with cum. strat.
1:55	27.05	23.0	21.9	27.05	1:57	1:56	27.05	2884	.1067	19.8	86.8	
1:57												Clouds above breaking away rapidly.
1:59												In clear sunshine clouds below seem pure white.
1:59	26.45	22.2	21.0	26.40	2:01	2:00	26.42	3491	.1019	18.8	85.8	
2:04	26.08	25.1	21.9	25.79	2:07.5	2:06	25.94	3961	.0863	15.2	63.9	Sun shines warm like summer.
2:07.5												Sky partly covered with thin circu. clouds.
2:08	25.73	21.4	19.2	25.81	2:10.3	2:09.2	25.77	4130	.0848	14.8	73.8	
2:10												Earth seen dimly through clouds.
2:12												Can hear trains distinctly: heard report of a gun.

TABLE XII—Continued.

Observations.						Results.						
Time. 15th Mer.	Cor. Bar. Reading.	Temperature. Dry Bulb.	Temperature. Wet Bulb.	Cor. Bar. Reading.	Time. 75th Mer.	Mean Time, 75th Mer.	Mean Bar. Reading.	Altitude.	Vapor Tension.	Dew Point.	Relative Humidity.	Remarks.
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In.	F.	P. ct.	
2:12	25.78	22.4	19.2	25.62	2:14	2:13	25.70	4200	.0732	11.5	61.2	
2:14												Moving N.W. about one-half as fast as clouds below.
2:20	25.49	23.2	20.0	25.50	2:23	2:21.5	25.55	4350	.0775	12.8	62.5	
2:29	25.85	23.0	20.2	25.82	2:31.5	2:30	25.84	4060	.0783	13.0	63.7	Sky becoming more hazy.
2:32	25.97	22.0	21.2	26.72	2:35	2:33.5	26.34	3567	.1064	19.7	94.7	
2:36												Enter cloud from above.
2:36	26.95	20.2	20.5	27.11	2:38.5	2:37.2	27.03	2903	.1088	20.2	100.0	Letting out sand.
2:39	27.32	19.1	18.9	27.55	2:41	2:40	27.44	2516	.1005	18.5	100.0	
2:41												Below cloud.
2:41.5	28.00											No. 1 located.
2:48.5	29.45	24.0	21.5	29.45	2:50	2:49.2	29.45	704	.0882	15.6	68.4	About 300 feet above ground; talking with people below.
2:50	29.45	23.7	21.5	29.65		2:51	29.55	.611	.0940	17.0	74.1	
	29.65											About 75 feet above ground.
2:54												Broke min. therm. by drag rope catching.
2:54	29.65	24.3	21.9	29.55	2:56	2:55	29.60	569	.0922	16.6	74.0	
2:58	29.50	23.7	21.5	29.31	3:00	2:59	29.40	743	.0940	17.0	74.1	
3:01	29.15	20.9	19.7	28.60	3:02.5	3:01.8	28.88	1202	.0931	16.8	83.3	
3:03	28.45	18.7	18.0	27.95	3:04.5	3:03.8	28.20	1814	.0910	16.3	89.3	
3:05.5	27.65	15.4	15.8	27.41	3:07.5	3:06.5	27.53	2432	.0873	15.4	100.0	Entering clouds, very fine light snow or [frozen vapor.
3:07.5	27.41											
3:11.3	27.55	15.2	15.6	27.55	3:13	3:12	27.55	2413	.0865	15.2	100.0	Ice in fine particles.
3:14	27.55	16.4	16.7	27.70	3:17	3:15.5	27.62	2348	.0914	16.4	100.0	

TABLE XII—Concluded.

Observations.						Results.						
Time. 15th Mer.	Cor. Bar. Reading.	Temperature. Dry Bulb.	Temperature. Wet Bulb.	Cor. Bar. Reading.	Time. 75th Mer.	Mean Time, 75th Mer.	Mean Bar. Reading.	Altitude.	Vapor Tension.	Dew Point.	Relative Humidity.	Remarks.
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In.	°F.	p. ct.	
3:20	......	......	......	......	......	......	......	......	......	......	......	No. 2; crossing R. R, see through breaks in cloud.
3:21	27.10	17.3	17.7	26.95	3:23	3:22	27.02	2912	.0953	17.3	100.0	We cannot see the earth but hear people hallooing to us.
3:23.5	26.95	18.0	18.4	26.70	3:28	3:25.5	26.82	3103	.0984	18.0	100.0	
3:23.5	......	......	......	......	......	......	......	......	......	......	......	Top surface of cloud, sun obscured between dense layers of stratus cloud.
3:31	26.53	18.1	18.4	26.45	3:34	3:32.5	26.49	3422	.0984	18.1	100.0	
3:36.5	26.30	19.2	19.0	26.53	3:39	3:38	26.42	3490	.1012	18.6	97.4	
3:39	......	......	......	......	......	......	......	......	......	......	......	Entering cloud from above.
3:41	26.45	18.9	18.7	26.57	......	3:42.5	26.51	3402	.0999	18.3	96.3	Cloud breaks away as we descend.
3:46	26.85	......	......	......	......	......	......	......	......	......	......	Entering cloud from above.
3:46	26.85	17.9	17.4	26.82	3:48	3:47	26.84	3082	.0906	16.2	92.4	Still in edge of cloud.
3:52	27.35	14.0	14.3	27.60	3:55	3:53.5	27.48	2478	.0818	14.0	100.0	In cloud.
3:55	......	......	......	......	......	......	......	......	......	......	......	Lower edge of cloud.
3:57	28.05	......	......	......	......	......	......	......	......	......	......	No. 3.
4:01	28.85	......	......	......	......	......	......	......	......	......	......	On level with high hill in front.
4:01	28.85	18.6	17.4	28.55	4:03.5	4:02.2	28.70	1363	.0827	14.2	81.9	About 500 feet above the ground.
4:07	28.45	17.3	16.7	28.27	4:11	4:09	28.36	1668	.0852	14.9	89.8	
4:25	......	......	......	......	......	......	......	......	......	......	......	Landed in Union Tp. Berks Co., Pa.
4:38.5	29.18	22.5	20.5	......	......	......	......	936	.0893	15.9	73.8	On ground Union Tp. Berks Co., Pa., 3 miles south of Birdsboro, Pa.

TABLE XIII.—*Observations taken during the third ascension, made March 27, 1885, from Girard College Grounds, Philadelphia, Pa.*

Observations.						Results.						Remarks.
Time. 75th Mer.	Cor Bar. Reading.	Temper-tures. Dry Bulb.	Temper-tures. Wet Bulb.	Cor. Bar. Reading.	Time. 75th Mer.	Mean Time, 75th Mer.	Mean Bar. Reading.	Altitude	Vapor Tension.	Dew Point.	Relative Humidity.	
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In.	°F.	p. ct.	
12:18	29.81	51.1	44.7	......	......	......	29.81	100	.2258	37.6	66.8	On ground at Girard College, Phila., Pa.
12:27	......	......	......	......	......	......	......	......	......	......	......	Started.
12:27	29.81	48.2	42.7	28.65	12:30	12:29	29.23	639	.2150	36.4	54.9	Enter haze.
12:30	28.55	47.7	42.4	27.60	12:33	12:31	28.07	1749	.2179	36.7	66.4	
12:34	27.26	47.4	42.7	27.14	12:36	12:35	27.20	2608	.2281	37.9	71.9	
12:37	27.07	46.5	42.8	26.95	12:41	12:39	27.01	2800	.2382	39.0	75.5	
12:42	26.88	46.4	42.5	26.89	12:45	12:43	26.89	2922	.2326	38.4	77.1	
12:45	26.83	45.9	42.4	26.67	12:48	12:56	26.75	3063	.2352	38.7	81.7	
12:50	26.78	......	......	......	......	......	......	......	......	......	......	No. 1: still in haze.
12:55	26.27	44.0	40.5	26.02	12:58	12:56	26.15	3680	.2172	36.6	78.7	
12:59	25.87	......	......	......	......	......	......	......	......	......	......	No. 2.
12 59 7	25.82	42.9	37.7	25.77	1:02.2	1:01	25.80	4044	.1799	31.8	68.2	
1:03	25.68	41.7	36.5	25.49	1:06	1:4.5	25.59	4263	.1667	30.0	66.4	
1:08	25.63	......	......	......	......	......	......	......	......	......	......	No. 3.
1:08	25.63	40.4	39.5	25.49	1:11.3	1:10	25.56	4285	......	......	......	
1:11.3	25.49	......	......	......	......	......	......	......	......	......	......	Over the Delaware at Trenton.
1:14	25.22	39.7	35.5	25.28	1:18	1:16	25.25	4617	.1706	30.5	69.6	
1:19	25.24	40.3	35.7	25.10	1:21	1:20	25.17	4704	.1790	31.7	71.3	
1:22	25.00	39.7	35.1	24.93	1:23.5	1:23	24.97	4921	.1612	29.2	65.8	
1:27.7	25.42	41.4	36.1	25.24	1:31	1:29.3	25.33	4536	.1621	29.3	62.1	
1:31	25.24	......	......	......	......	......	......	......	......	......	......	No. 4.
1:32	25.13	39.7	34.5	24.92	1:34.8	1:33.4	25.02	4866	.1522	27.8	62.1	

TABLE XIII.—Concluded.

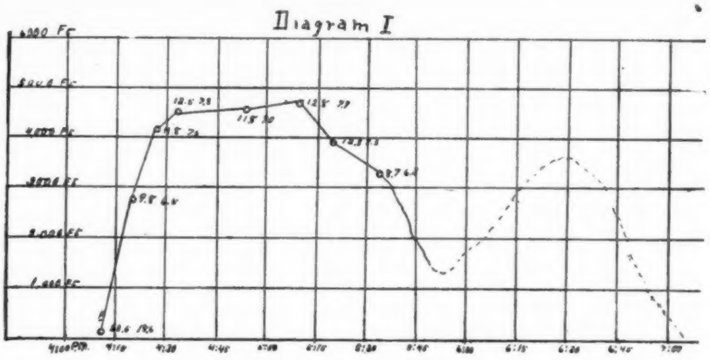
Observations.						Results.						Remarks.
Time, 75th Mer.	Cor. Bar. Reading.	Temper-tures.		Cor. Bar. Reading.	Time, 75th Mer.	Mean Time, 75th Mer.	Mean Bar. Reading.	Altitude.	Vapor Tension.	Dew Point.	Relative Humidity.	
		Dry. Bulb.	Wet Bulb.									
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In.	°F.	p. ct.	
1:35.5	24.88	38.7	34.5	24.90	1:37.8	1:36.8	24.89	5004	.1424	26.3	60.6	
1:38.5	24.77	38.4	33.7	24.61	1:41	1:39.8	24.69	5219	.1524	27.8	65.4	
1:43	24.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Located point No. 5.
1:43	24.23	36.6	32.0	23.98	1:45.8	1:44.4	24.10	5867	.1400	25.9	64.6	
1:47	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Opposite Brunswick.
1:48.7	24.37	36.1	32.4	24.17	1:52.7	1:50.7	24.27	5673	.1506	27.6	70.7	
1:55.8	23.97	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	No. 6, clouds forming below us.
1:58	23.75	34.6	30.7	23.81	2:00.7	1:59.3	23.78	6217	.1375	25.5	68.4	
2:01.7	23.87	35.1	31.4	24.02	2:04	2:02.3	23.91	6038	.1437	26.5	70.5	
2:05	24.30	35.8	33.5	24.53	2:06.5	2:05.8	24.41	5518	.1713	30.6	67.3	
2:07.5	24.87	38.7	37.7	25.55	2:11	2:09.3	25.21	4656	.2166	36.6	92.2	
2:11.8	26.05	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Clouds forming in front.
2:11.8	26.05	40.4	38.7	27.05	2:14	2:13	26.55	3255	.2180	36.7	86.9	
2:15	28.05	49.0	44.0	28.85	2:16.5	2:15.8	28.45	1384	.2360	38.8	67.8	
2:19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Landed.
2:25	29.80	53.0	47.2	.....	.....	.....	29.80	25	.2626	41.5	65.2	On ground near Tremley, N. J., three miles east of Rahway, N. J.

TABLE XIV.—*Observations taken during the Fourth Ascension made April 16, 1885, from Girard College Grounds, Philadelphia, Pa.*

Observations.						Results.						
Time, 75th Mer.	Cor. Bar. Reading.	Temperatures. Dry Bulb.	Temperatures. Wet Bulb.	Cor. Bar. Reading.	Time, 75th Mer.	Mean Time, 75th Mer.	Mean Bar. Reading.	Altitude.	Vapor Tension	Dew Point.	Relative Humidity.	Remarks.
P. M.	In.	°F.	°F.	P. M.	In.	P. M.	In.	Feet.	In.	°F.	p. ct.	
12:02	29.89	50.5	41.5	......	......	......	29.89	100	.1644	29.6	44.8	In sun, ground Girard Col., Phila., Pa
12:02	29.89	49.7	41.0	......	......	......	......	......	.1614	29.2	45.2	In shade, each record is the mean of several readings.
12:21	......	......	......	......	......	......	......	......	......	......	......	Started.
12:21	29.89	49.2	39.4	29.15	12:23	12:22	29.52	441	.1376	25.5	39.3	
12:23	29.00	36.7	32.4	27.15	12:25	12:24	28.07	1797	.1397	25.8	64.1	
12:26	27.00	33.1	29.7	26.79	12:30	12:28	26.90	2939	.1312	24.4	69.3	
12:30	......	......	......	......	......	......	......	......	......	......	......	Over public buildings, Phila., Pa,
12:33	26.33	34.1	28.7	26.15	12:36	12:35	26.24	3608	.1063	19.7	54.1	
12:38	25.85	31.5	29.7	26.10	12:41	12:40	25.98	3868	.1476	27.1	83.4	Thermometer in shade of balloon.
12:41	26.10	32.5	28.2	26.03	12:43	12:42	26.06	3789	.1136	21.2	61.6	Thermometer in shade of balloon.
12:49	25.77	......	......	......	......	......	......	......	......	......	......	No. 1. Over Delaware River.
12:51	25.70	31.0	27.2	25.75	12:54	12:53	25.72	4141	.1127	21.0	65.2	Thermometer in shade of balloon.
12:56	25.70	32.5	27.0	25.59	12:59	12:58	25.64	4226	.0948	17.2	51.3	Thermometer in shade of balloon.
12:59.2	25.61	32.7	27.3	25.51	......	1:00(?)	25.56	4310	.0985	18.0	53.0	Thermometer in shade of balloon.
1:05.6	25.66	......	......	......	......	......	......	......	......	......	......	No. 2. Felt gust of wind from east.
1:05.6	25.66	32.4	28.9	25.59	1:10.7	1:08	25.62	4250	.1274	23.7	69.2	In sunshine.
1:13	25.79	31.5	27.9	26.08	1:19	1:16	25.94	3900	.1186	22.1	67.1	In sunshine.
1:13	......	......	......	......	......	......	......	......	......	......	......	Wet the wet.bulb thermometer.
1:20	26.38	33.3	29.7	26.63	1:23	1:21.5	26.50	3342	.1300	24.2	68.1	In shade.
1:26	28.22	......	......	......	......	......	......	......	......	......	......	Wet the wet-bulb thermometer.
1:30	28.55	......	......	......	......	......	......	......	......	......	......	No. 3.

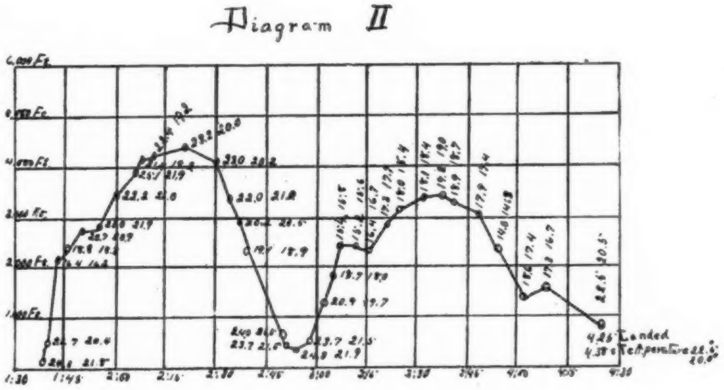
TABLE XIV—Concluded.

Observations.						Results.						
Time, 75th Mer.	Cor. Bar. Reading.	Temperature. Dry. Bulb.	Temperature. Wet Bulb.	Cor. Bar. Reading.	Time, 75th Mer.	Mean Time 75th Mer.	Mean Bar Reading.	Altitude.	Vapor Tension.	Dew Point.	Relative Humidity.	Remarks.
P. M.	In.	°F.	°F.	In.	P. M.	P. M.	In.	Feet.	In	°F.	p. ct.	
1:30	28.55	46.4	38.7	29.28	1:32 5	1:31.2	28.92	1001	.1540	28.1	48.8	In shade.
1:34	29.07	47.2	38.8	28.97	......	1:35(?)	29.02	907	.1472	27.0	45.3	In shade.
1:38	29.00	47.0	38.7	28.99	1:41	1:40	29.00	927	.1471	27.0	45.6	In shade.
1:42.5	28.57	43.2	36.0	27.87	1:45	1:44	28.22	1665	.1378	25.5	49.4	In shade.
1:45.2	27.65	38.2	33.2	27.09	1:47.2	1:46.2	27.37	2485	.1395	25.8	60.4	In shade.
1:47.5	27.05	38.3	33.7	27.07	1:50	1:48.8	27.06	2793	.1459	26.9	62.9	In sunshine.
1:51	26.69	36.2	32.7	26.73	1:54	1:52.5	26.71	3139	.1528	27.9	71.6	Gusts of wind blowing apparently upward.
1:55	26.81	37.2	33.2	26.84	1:58	1:56.5	26.82	3030	.1510	27.6	68.1	In sunshine.
2:00	26.78	36.7	33.2	27.13	2:03	2:01.5	27.00	2840	.1561	28.4	71.6	In sunshine.
2:05 3	28.43	47.1	38.7	28.73	2:08	2:06 7	28.58	1325	.1472	27.0	45.5	In sunshine.
2:10	28.85	......	......	......	......	......	......	......	......	......	......	No. 4.
2:10.7	28.95	49.7	40.7	29.07	......	2:12(?)	29.01	918	.1591	28.9	44.6	In sunshine.
2:16	29.32	51.2	41.2	29.27	2:18.3	2:17.1	29.30	647	.1536	28.0	40.8	In sunshine.
2:21	28.88	48.1	39.4	28.75	2:23	2:22	28.81	1107	.1513	27.7	45.0	In sunshine. Balloon rose at this time without perceptible cause.
2:28	*	......	......	......	......	......	......	......	......	......	......	Landed near Williamstown, N. J.
2:57	29.86	55.3	......	......	......	......	29.92	75	......	......	......	*The barometer read 29.86 on landing, but from the altitude of the place of landing it should have been 29.92. Apparently the instrument was injured by the shock of landing.



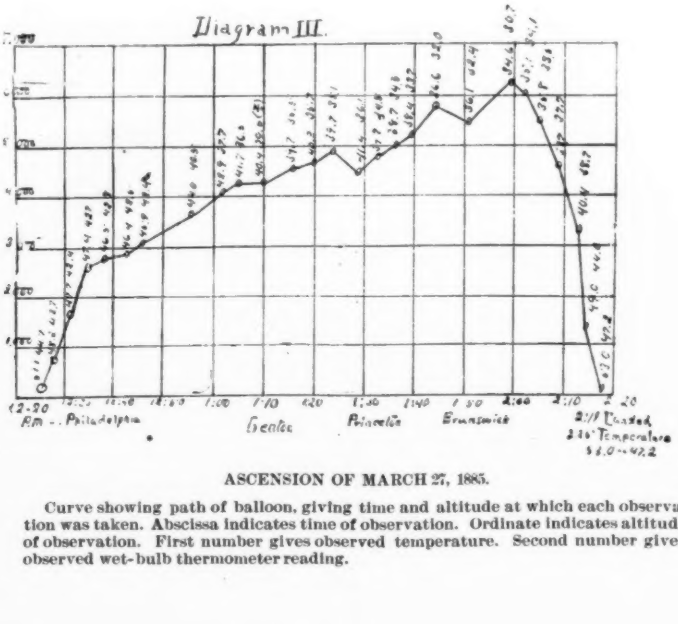
ASCENSION OF JANUARY 19, 1885.

Curve showing path of balloon, giving time and altitnde at which each observation was taken. Abscissa indicates time of observation. Ordinate indicates altitude of observation. First number gives observed temperature. Second number gives observed wet-bulb thermometer reading. The black line of the curve shows that portion of the route passed over before dark and located by actual observation. The dotted portion is the estimated path of balloon after dark.



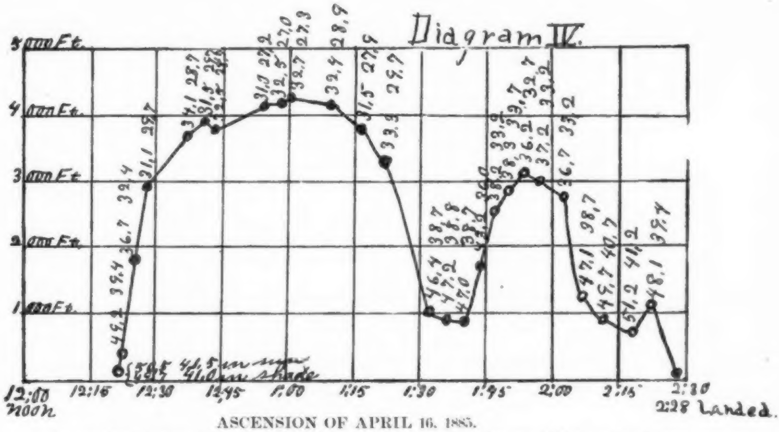
ASCENSION OF MARCH 13, 1885.

Curve showing path of balloon, giving time and altitude at which each observation was taken. Abscissa indicates time of observation. Ordinate indicates altitude of observation. First number gives observed temperature. Second number gives observed wet-bulb thermometer reading.



ASCENSION OF MARCH 27, 1885.

Curve showing path of balloon, giving time and altitude at which each observation was taken. Abscissa indicates time of observation. Ordinate indicates altitude of observation. First number gives observed temperature. Second number gives observed wet-bulb thermometer reading.



ASCENSION OF APRIL 16, 1885.

Curve showing path of balloon, showing time and altitude at which each observation was taken. Abscissa indicates time of observation. Ordinate indicates altitude of observation. Second number gives observed wet-bulb thermometer readings.

In this formula,

a = the time in minutes consumed in passing from one point to the next following.

x = the probable error in the velocity of air currents expressed in miles per hour, as given in the table.

The scale of the map used on the second voyage was twenty miles to the inch and consequently there was less accuracy in locating the points than on the other ascensions. The probable error in locating these points was assumed to be two miles, and the probable error in velocity was obtained in the same manner as before from the equation

$$x = \pm \frac{60}{a} \times 2.0\sqrt{2}\,.$$

(See Table XV.)

(9) *Temperature and Altitude.*—The rate of diminution of temperature for elevation was determined for each ascent in the following manner. The temperatures used are those given in table XVI, or the temperatures given in tables XI, XII, XIII, corrected for diurnal change of the air temperatures, during the observations, assuming the diurnal change to correspond with that observed at the earth's surface.

(See Table XVI.)

These observations are shown graphically for each ascension

TABLE XV.—*Showing direction and velocity of the currents of the air at different heights during each ascension.*

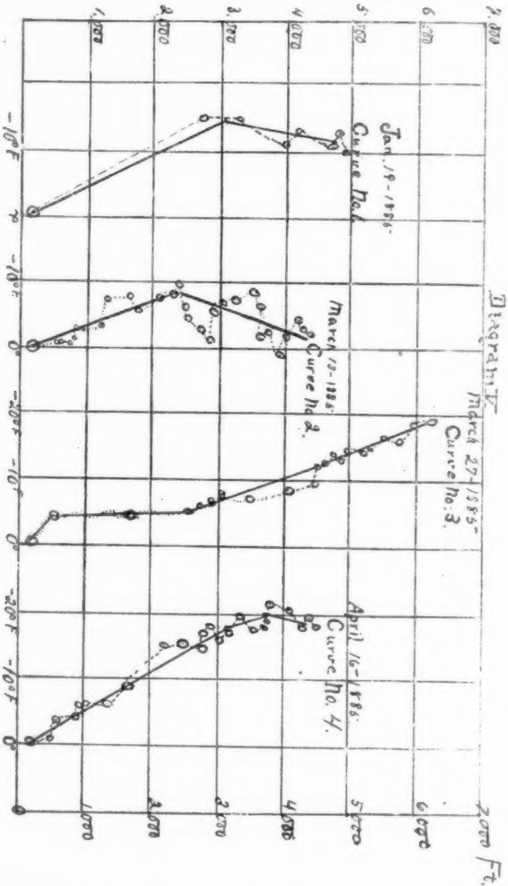
	Time. P. M., 75th Mer.		Altitude. Feet.		Dist.	Wind. Dir.	Wind. Vel	Prob. Error in Vel.
	From.	To.	From.	To.	Miles.		Miles per hour.	
I. First ascent, Jan. 19, 1885.	Starti'g.	4:12		100		NW	15	±0
	4:12	4:22	100	3000	2	NW	13	±4
	4:22	4:36	3000	4770	4	SW	17	±3
	4:36	4:58	4770	4670	4	SW	10	±2
	4:58	5:05	4670	4680	3	SW	26	±5
	5:05	5:14	4680	4450	4.5	NW	30	±5
	5:14	7:05	4450	50	40.2	NW	22	±0
	On landing wind was 10 to 15 miles.							
	Average velocity for voyage...........						19	±0
II. Second ascent, March 13, 1885.	Starti'g.	1:38		100		NE	15	±0
	1:38	2:41.5	100 4350	4350 1830	17	NE SE	16	±3
	2.41 5	3:20	1830 570	570 2350	9	E SE	14	±4
	3:20	3:57	2350 3500	3500 1780	10	SE	16	±4.5
	3:57	4:25	1780 1360	1360 940	5.5	E NE	12	±6
	On landing wind was 8 to 12 miles.							
	Average velocity for voyage.............						14	
III. Third ascent, March 27, 1885.	Starti'g.	12:27		100		SW	Lt.	
	12:27	12:50	100	3000	10	SW	26	±2
	12:50	1:08	3000	4300	12.5	SW	42	±2
	1:08	1:31	4300	4700	15	SW	39	±2
	1:31	1:43	4700	5760	8	SW	40	±3.5
	1:43	1:55.8	5760	6000	8	SW	38	±3
	1:56	2:19	6000	50	12.5	SW S E	32	±2
	On landing wind was light.							
	Average velocity during voyage.........						36	0
IV. Fourth ascent, April 16, 1885.	Starti'g.	12 21		100		N	15	
	12:21	12:49	100	4100	6.2	N NW	13	±2
	12:49	1:05.6	4100	4300	3.7	NW	13	±2
	1:05,6	1:30	4300	1300	3.5	N NW	10	±1.5
	1:30	2:10	1300 3100	3100 900	5.3	N NW	9	±1
	2:10	2:28	900	100	3.8	N NW	10	±2
	On landing wind was about 15 miles per hour.							
	Average velocity during voyage........						10.5	0.0

TABLE XVI.

Temperatures corrected for diurnal change, with the corresponding altitudes.

1st Ascent. Jan. 19, 1885.			2nd Ascent. Mar. 13, 1885.			3d Ascent. Mar. 27, 1885.			4th Ascent. April 16, 1885		
Temperature.		Altitude Above sea.	Temperature.		Altitude Above sea.	Temperature.		Altitude Above sea.	Temperature.		Altitude Above sea.
Observed.	Corrected.	Feet.	Observed.	Corrected.	Feet.	Observed.	Corrected.	Feet.	Observed.	Corrected.	Feet.
°F.	°F.		°F.	°F.		°F.	°F.		°F.	°F.	
23.5	23.5	100	24.3	24.3	100	51.1	51.1	100	49.7	50.5	100
9.8	9.9	2847	22.7	22.7	555	48.2	48.2	639	49.2	48.7	441
11.8	11.9	4144	16.4	16.4	2155	47.7	47.6	1749	36.7	36.0	1797
12.5	12.8	4476	18.3	18.3	2441	47.4	47.2	2608	33.1	32.4	2936
11.8	12.3	4567	20.7	20.6	2780	46.5	46.3	2800	34.1	33.2	3608
12.8	13.5	4749	23.0	22.9	2884	46.4	46.1	2922	31.5	31.3	3868
12.3	13.1	3941	22.2	22.1	3490	45.9	45.6	3063	32.5	32.2	3789
8.7	9.7	3319	25.1	24.9	3960	44.0	43.5	3680	31.0	30.4	4141
21.1	23.5	50	21.4	21.2	4130	42.9	42.4	4044	32.5	31.8	4226
....	....	....	22.4	22.2	4200	41.7	41.1	4263	32.7	31.9	4310
....	....	....	23.2	22.9	4350	40.4	39.7	4285	32.4	30.6	4250
....	....	....	23.0	22.7	4060	39.7	38.9	4617	31.5	29.5	3900
....	....	....	22.0	21.7	3567	40.3	39.4	4704	33.3	31.9	3342
....	....	....	20.2	19.8	2900	39.7	38.7	4921	46.4	44.7	1000
....	....	....	19.1	18.7	2516	41.4	40.4	4536	47.2	45.4	900
....	....	....	24.0	23.6	700	39.7	38.6	4866	47.0	45.1	930
....	....	....	23.7	23.2	611	38.7	37.5	5000	43.2	41.1	1665
....	....	....	24.3	23.8	569	38.4	37.2	5220	38.2	36.0	2485
....	....	....	23.7	23.2	740	36.6	35.3	5870	38.3	35.2	2793
....	....	....	20.9	20.4	1200	36.1	34.7	5670	36.2	33.1	3140
....	....	....	18.7	18.2	1810	34.6	33.0	6220	37.2	33.9	3030
....	....	....	15.4	14.8	2430	35.1	33.4	6040	36.7	33.4	2840
....	....	....	15.2	14.6	2410	35.8	34.1	5520	47.1	43.7	1325
....	....	....	16.4	15.8	2350	38.7	37.0	4656	49.7	46.1	920
....	....	....	17.3	16.7	2912	40.4	38.8	3255	51.2	47.4	650
....	....	....	18.0	17.3	3100	49.0	48.0	1384	48.1	44.2	1100
....	....	....	18.1	17.4	3420	53.0	51.1	25	55.3	50.5	75
....	....	....	19.2	18.4	3490	....	....	....	....	....	....
....	....	....	18.9	18.1	3400	....	....	....	....	....	....
....	....	....	17.9	17.1	3080	....	....	....	....	....	....
....	....	....	14.0	13.1	2480	....	....	....	....	....	....
....	....	....	18.6	17.7	1360	....	....	....	....	....	....
....	....	....	17.3	16.3	1670	....	....	....	....	....	....
....	....	....	22.5	21.3	930	....	....	....	....	....	....

separately in diagram V, where the ordinates show the elevations, and the abscissas the changes in temperature; the temperatures at the surface being the zero of the scale, and the slant to the left indicating a decrease in temperature.



Showing changes in temperature for elevation: ordinates show altitudes; abscissas show differences of temperature.

In these diagrams each individual observation is given, except when they are very numerous and occurring at too close intervals in height to be easily represented. In such cases averages have

been taken of all observations recorded within fifty feet. The broken lines show the general rate of diminution for distinct portions of the separate ascents. In these portions the observaions which most nearly approximate to a straight line were grouped together and the average rate of decrease was determined for each group, assuming the equation:

$$\frac{H-h}{100}x = (T-t) + r$$

in which

x = change in temperature for each hundred feet of elevation.

H= altitude in feet at which observation was taken.

h = elevation of the base of the group in which the observation is included.

T = corrected temperature (table XVI) at altitude H.

t = corrected temperature (table XVI) at altitude h.

r = residual.

An equation was formed for each observation, except in cases where several observations occurred within fifty feet, when an average value was used, and weight was given to the equation in proportion to the number of observations of which it was the mean. By combining the several equations of each group, by the process of least squares, a mean value of x for the group was obtained.

In table XVII are given the rates of change in temperature for 100 feet as determined for each group of the different ascents:

So few ascents were made and the altitudes attained were so slight that the influences of local causes, such as the season of the year, character of the weather, time of day, etc., were great in comparison to those due to mere elevation. For this reason, the rates of decrease of temperature for elevation, as determined from these observations, are to be considered as contributions to the study of the special weather of the respective dates, and not as bearing particularly upon the questions involved in the general circulation of the air, and the normal annual average vertical gradient for the whole atmosphere.

(See Table XVII.)

TABLE XVII.

Ascension.	Group.	Height above sea level. From.	To.	Rate of change for 100 feet.	State of Sky.
I. Jan. 19.	I.	100	3300	$-0.^\circ 46$	Light haze.
	II.	3300	4600	+0.36	
II. Mch. 13.	I.	100	2400	$-0.^\circ 41$	Covered with low stratus.
	II.	2400	3450	+0.46	Enveloped in cloud.
	III.	3450	4350	+0.41	Cl'dless, partly cl'dy and cl'dy at times.
III. Mch. 27.	I.	100	650	−0.56	Covered with high stratus.
	II.	650	2600	−0.04	
	III.	2600	4700	−0.41	
	IV.	4700	6200	−0.38	
IV. Apr. 16.	I.	100	1600	−0.61	Cloudless.
	II.	1600	3100	−0.58	
	III.	3100	3900	−0.28	
	IV.	3900	4300	+0.11	